



# Search for a new baryonic state decaying to $pK_S^0$

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## Abstract

We report on a new ZEUS search for a narrow state decaying into  $p(\bar{p})K_S^0$ , which was previously claimed by the ZEUS collaboration. In the present search, which uses much increased statistics, no evidence for this state is found. Limits on the cross section for such a state are given.

## 1 Introduction

During the early 2000 years, several experiments reported the discovery of “exotic” hadronic particles that apparently consisted of more than the normal two or three quarks or antiquarks. The results of the different experiments were not all consistent, and the area was left unresolved. Among the reported results was a paper from the ZEUS collaboration [1], in which the channel  $pK_S^0$  was studied together with the corresponding antiproton state. Evidence was given (fig. 1) for a narrow peak in this channel, at a mass of 1.5215 GeV, using data taken in the first running period of HERA during the years 1996-2000. Such a state would be a pentaquark state

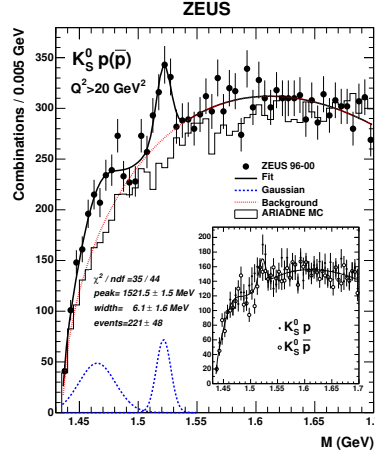


Figure 1: The (anti)proton-kaon mass spectrum obtained by ZEUS in its earlier publication, interpreted as showing a narrow state at 1.51215 GeV.

$uudd\bar{s}$ , and was consistent with the  $\Theta$  state reported by other groupss, although it was not confirmed by the H1 experiment at HERA [2].

Recently, the LHCb collaboration have announced the discovery of two pentaquark states at the much higher masses of 4.38 and 4.45 GeV [4]. The time was therefore ripe for a re-examination of the state reported by ZEUS. This presentation, whose results have been published in more detail [3], gives an analysis of the same channel using the much larger data set collected during the second HERA run period 2003-2007. In addition, the charged-particle tracking system was upgraded and used improved analysis software.

## 2 Analysis procedure

A data set corresponding to  $358 \text{ pb}^{-1}$  was used in the present work, approximately three times the previously used integrated luminosity. The proton was identified using ionisation deposited in the ZEUS central tracking detector (CTD) as before, augmented by similar information available from the new silicon micro vertex detector (MVD). In the following account, any mention of a  $pK_S^0$  state always includes the consideration of the corresponding charge conjugate state  $\bar{p}K_S^0$ . Protons at 920 GeV were collided with electrons or positrons at 27.5 GeV, and the state under investigation was sought in deep inelastic scattering events with a well-identified scattered electron or positron. The virtuality of the exchanged photon was chosen to be in the range  $20 < Q^2 < 100 \text{ GeV}^2$ , and the scattered electron or positron had to have a minimum energy of 10 GeV. The final-state particle had to be well contained within the detector, as determined by the sum of their measured energy and longitudinal momentum.

The  $K_S^0$  contained in the sought state was identified in the normal way by observing two charged tracks of opposite sign, produced in the region of the detector with good tracking identification, and forming a common vertex such that the reconstructed  $K_S^0$  pointed towards the primary vertex of the event. The requirement was made for a decay length of at least 0.5 cm, projected on to the plane transverse to the beam line. Each contributing track had to have a transverse momentum of at least 0.15 GeV, and that of the combination had to be at least 0.3 GeV. Cuts were made to eliminate converted electrons and lambda baryons. A clean  $K_S^0$  signal was seen with negligible background, corresponding to 0.31 million events with a  $K_S^0$ .

Proton identification was performed using the ionisation energy in the CTD and the MVD, and was used to select proton candidates in the momentum range 0.2 to 1.5 GeV. It was applied to all charged tracks that passed through both detector system, ignoring tracks that had been assigned to  $K_S^0$  mesons. The two detectors were used to confirm each other's ionisation signals and provide a satisfactory proton identification when both detectors were employed together. The probability for identifying a given proton correctly varied from 0.8 at low  $p_T$  values, falling to 0.2 at the upper end of the accepted range. Pion contamination was evaluated using a selected  $K_S^0$  sample, and was 10-100 times better in the present measurement than in the earlier measurement. Pions identified as protons contribute to the background in the mass spectrum under study.

In order to verify that a narrow baryon-like signal was detectable using the present method, the  $pK_S^0$  mass spectrum was measured for a large sample of photoproduction events obtained with ZEUS. A clear signal for the  $\Lambda_c$  baryon at 2.3 GeV was observed.

### 3 Results

Figure 2 presents  $pK_S^0$  mass spectra obtained in the present search. Figure 2(a) shows the spectrum for a broad range of mass values, and exhibits no narrow features except for an indication of the  $\Lambda_c$  baryon at 2.3 GeV, which is seen more clearly in photoproduction events (b). Figure 2(c) shows the same mass spectrum as (a), but on an expanded scale, and includes the size of a signal at 1.5215 GeV that would be expected if the fitted feature in the previous ZEUS analysis were found in the present data sample. In (d), the shape of the mass spectrum is presented under conditions of event selection that resembled those of the previous ZEUS analysis.

It is evident that the previously claimed narrow state is not confirmed in the present data. Instead, it would seem that the shape of the mass spectrum in the previous data was not modelled appropriately, and the apparent presence of a narrow peak was a consequence of this together with a statistical fluctuation on the data.

Given this conclusion, the ZEUS Collaboration have calculated experimental limits on the production of a narrow state  $X$  in the in the range of mass values that have been measured. Upper limits for the cross section times the branching ratio into  $pK_S^0$  are evaluated for three hypotheses on the width of  $X$ : a fixed value of 6.3 MeV, corresponding to the width of the fitted state in the earlier ZEUS paper, a mass-varying width corresponding to the ZEUS detector resolution, and also twice

## ZEUS

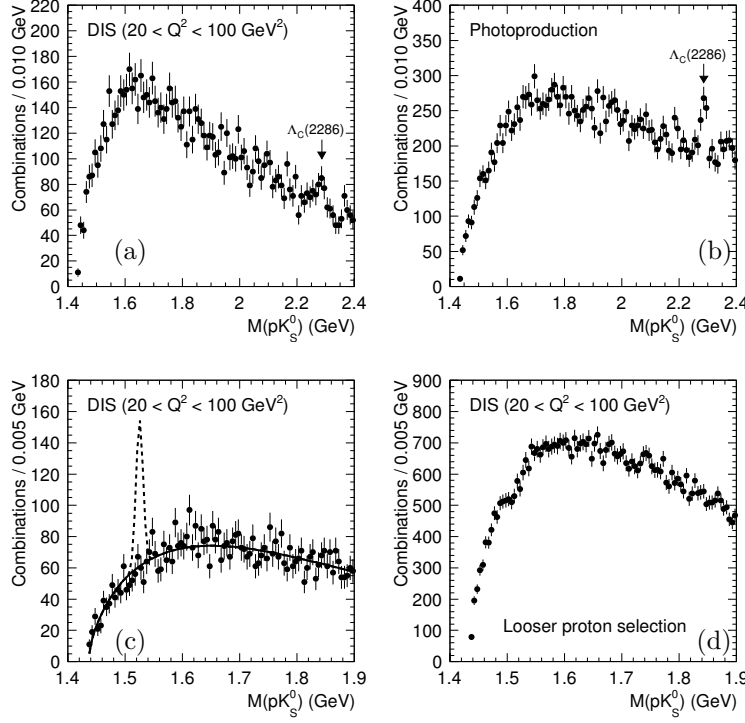


Figure 2: (a) (Anti)proton-kaon mass spectrum measured in DIS events with event selections as in the text; (b) mass spectrum measured in photoproduction events; (c) mass spectrum as (a) with expanded horizontal scale; (d) mass spectrum measured under conditions resembling those of the earlier ZEUS result.

this value. The final case roughly approximates to the measurement resolution of the H1 detector, in order to make a comparison to the published H1 cross-section limits [2].

The hypothesised state  $X$  was simulated using the Monte Carlo generator RAPGAP 3.1030, and the normal GEANT-based simulation of the ZEUS apparatus. The known state  $\Sigma^+(1189)$ , which decays into  $pK^0$ , was replaced by a similar state whose mass was assigned a series of values in data sets that covered the relevant range of masses under study. The normal branching ratios for the kaon decay into  $K_S^0$  and into  $\pi^+\pi^-$  were taken, and . Cross section limits were calculated for production within the kinematic limits  $20 < Q^2 < 100 \text{ GeV}^2$ ,  $0.5 < p_T(X) < 3.0 \text{ GeV}/c$ ,  $|\eta(X)| < 1.5$ . A polynomial-based background spectrum shape was used. Systematic effects gave an uncertainty of approximately 10% on the resulting upper limits, the biggest contribution coming from the modelling of the transverse

## ZEUS

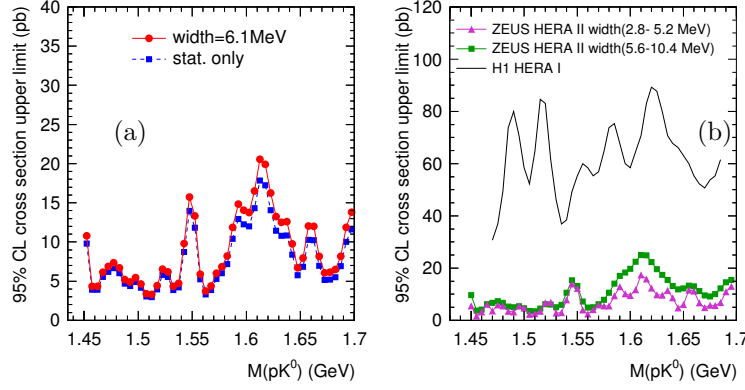


Figure 3: 95% confidence level upper limits for the production cross section of a state  $X$  times its branching ratio for  $X \rightarrow pK_S^0$  for (a) fixed 6.1 MeV width and (b) detector-resolution width models.

momentum of the state  $X$ .

The resulting cross-section limits at the 95% confidence level are shown in fig. 3, in comparison with the higher values that had been obtained by H1.

## 4 Summary

A new search has been made, by the ZEUS Collaboration at HERA, for a narrow state decaying into  $p(\bar{p})K_S^0$  whose observation was previously claimed by the ZEUS collaboration. In the present search, which uses much increased statistics, no evidence for this state is found. Limits on the cross section for such a state are given.

## References

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- [2] H1 Collaboration, Phys. Lett. **bf B 639**, 202 (2006).
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